A new conceptual framework based on the ECSI model to support Axiomatic Design

Irene Ferreira
School of Technology and Management, Polytechnic Institute of Leiria, Portugal

J. Sarsfield Cabral
Engineering Faculty, Porto University, Portugal

Pedro Saraiva
Chemical Engineering Department, Coimbra University, Portugal

ABSTRACT: According with Axiomatic Design (AD) theory, the world of design is made up of four domains: the customer domain, the functional domain, the physical domain and the process domain. Therefore, to proceed in the design process, firstly, it's necessary to determine the Customer's Attributes (CAs), established in the Customer domain, and translate them into specific requirements, the Functional Requirements (FRs), formalized in the functional domain. This task is considered essential because a major reason for customer dissatisfaction is that the design specifications quite often do not adequately link to customer use of the product, a fact which is being pointed out as the most common cause for product design failures [1-2]. The European Customer Satisfaction Index (ECSI), as a Structural Equation Model (SEM), links customer satisfaction to its main drivers and consequences in terms of causal relationships. We will therefore introduce in this paper a new conceptual framework, aimed at addressing the development and validation of a model based on ECSI that supports the determination of the critical-to-satisfy (CTS) requirements, which are then used to determine the FRs. In order to validate the proposed approach, it was applied to the Portuguese plastic injection moulds sector.

1 INTRODUCTION

Suh [3] defined Design as "the creation of synthesized solutions in the form of products, processes or systems that satisfy perceived needs through the mapping between the FRs in the functional domain and the Design Parameters (DPs) of the physical domain, through the proper selection of DPs that satisfy FRs". So, to design or redesign a product, firstly it is necessary to determine the CAs and translate them into specific requirements, the FRs. This task is an essential task to achieve successful products, because if it's not done correctly, designers initiate designs without fully understanding customer requirements, thus leading to less satisfactory products. Generally customer needs are defined in an imprecise language, which can be easily misunderstood by the designer team. Furthermore, the designer team must consider that, typically customers have only a superficial understanding of the many functions that a product supports and they lack experience in identifying and expressing their desirable requirements. Thus, it is hard to acquire accurately and completely the CAs and convert them into a successful design. Therefore, the ability to capture customer requirements correctly and succinctly is of paramount importance. To tackle this issue, several approaches have been developed. In this paper we present one new approach, which aims to accurately capture the requirements expressed by customers and then convert them into FRs. Hence, by the zigzagging process established by the AD methodology, it will be possible to map hierarchically these FRs into DPs, in order to create several alternative product solutions.

2 CONCEPTUAL FRAMEWORK

The new conceptual framework is proposed with the main goal of establishing links between the customer and functional domains, as it was recommended by Suh [3]. Basically, this approach encompasses two sequential steps. The first one consists in an exploratory stage, qualitative research, with the aim of obtaining, understanding, and prioritizing customer wants and needs. The capture of CAs, usually conducted by Market Research, is generally gathered in two ways: through indirect information (collected from consumer labs, trade journals, competitive benchmarking and forecasts, etc.) and through direct customer engagement (obtained from interviews, focus groups, customer councils, field observations, etc.).

In our approach, firstly one has to identify who are the “keystone” customers by performing a Customer Value Chain Analysis (CVCA). Then, through semi-structured customer interviews and by gemba studies, the spoken and unspoken demands are identified. Afterwards, the data gathered are used to perform the second phase of this framework. At this stage, a survey was developed in order to validate and generalize the findings, i.e., to confirm the customer needs identified by qualitative research, quantify the relative importance of needs, and, finally, to evaluate the factors that contribute towards the global satisfaction of customers. Therefore, the questionnaire was developed based on the European Customer Satisfaction Index (ECSI) model. The ECSI system is based on a structural model that monitors costumer satisfaction. The main goal of this index is to develop a methodology that allows for comparability and measures the quality of the economic output, as perceived by the market. Thus, this index is understood (at least indirectly) as an indicator of costumer assets in the market, and allows for the comparison between companies within the same sector, that operate in the same country, or at a macroeconomic level. Finally, the last task to perform at this stage concerns building the House of Quality (HOQ), in order to translate the critical CAs identified into FRs.

2.1 *European Customer Satisfaction Index (ECSI)*

Currently, Customer Satisfaction (CS) and their retention are key issues for organizations in today’s competitive market place. Therefore, CS evaluation has become a vital concern for companies and organizations in order to improve product and service quality and maintain customers’ loyalty. It is indeed hard to define CS and even harder to measure it. CS must be considered as a latent construct that is not observed directly and can only be estimated through other indicators. Bearing this in mind, the European Commission, in conjunction with the European Organization for Quality, the European Foundation for Quality Management and the Customer Satisfaction Index University Network, developed an initial CS SEM. This model is aimed at measuring and explaining CS and customer loyalty, providing useful information for improving the performance of companies and serving as a benchmarking tool for the economies of different countries in Europe. The result of this work was the development of the ECSI model as a tool to evaluate customer asset, which is regarded as an important intangible value for organizations [4].

SEM techniques are based upon sets of linear equations used to specify phenomena in terms of their presumed cause-and-effect variables. Generally, these models are established for variables, latent variables, which cannot be measured directly (as customer satisfaction) and are operationalised by multiple indicators. The hypothesized cause-effect relationships, between variables, are described by parameters that indicate the magnitude of the effect (direct or indirect) that independent variables (either observed or latent) have over dependent variables (either observed or latent). By enabling the translation of these hypothesized relationships into testable mathematical models, SEM offers researchers a comprehensive method for the quantification and testing of theoretical models. Once a theory has been proposed, it can then be tested against empirical data. The process of testing a proposed theoretical model is commonly referred to as the "confirmatory" phase of SEM. Another aspect of SEM is the so-called "exploratory" mode, which allows for theory development and often involves repeated applications of the same data in order to explore potential relationships between variables of interest (either observed or latent). The ECSI model is based on a structural model with seven latent variables, which links CS to its main drivers (namely, company image, customer expectations, perceived quality and perceived value) and its main consequences (loyalty and complaints), in terms of casual relationships. The ECSI model adopted by Portugal measures the following dimensions, which can be observed in Figure 1 (www.ipq.pt/ecsi).

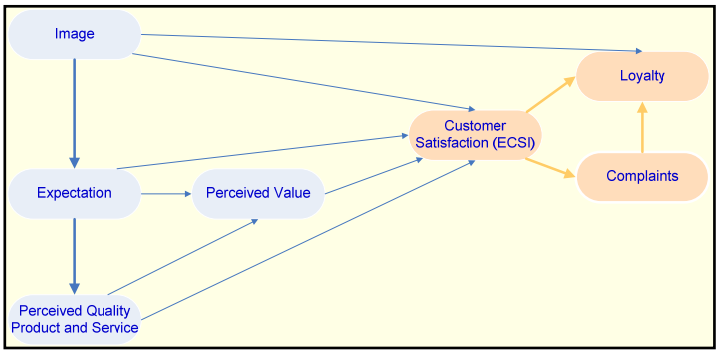

Figure 1. The ECSI Model adopted by Portugal.

As it is possible to see from the previous figure, customer satisfaction is the central variable of this model, having as antecedents or drivers the Image of the company, Customer Expectations, Perceived Quality of Products/Services and Perceived Value. The main consequences of customer satisfaction are Complaints and Customer Loyalty. As antecedents of customer satisfaction, one has Perceived Quality, which integrates product quality and service quality. Perceived Quality corresponds to the evaluation of recent consumption experiences of products (product quality) and experiences of associated services (service quality). Both types are expected to affect Satisfaction. Perceived Value is the perceived level of product quality and the price paid, which is expected to have a direct impact over Satisfaction and to be positively affected by Perceived Quality. Ex-

pectations include the information that customers have acquired in the past, regarding products and services offered by the company. In this model, it is assumed that this variable has a direct impact over Satisfaction and gets an indirect impact through Perceived Value and Perceived Quality. Finally, the variable Image embraces the global idea that customers have from the product or company. It is expected that Image will have a direct effect over Customer Satisfaction, Loyalty and Expectations. The consequences of consumer satisfaction considered in the ECSI model are Complaints and Loyalty. Complaints "measure" the complaints frequency and the manner in which the company manages these complaints. It is also assumed that Customer Satisfaction has a direct effect over this variable. Loyalty refers to customers' loyalty to the product or company. It is expected that Image, Customer Satisfaction and Complaints have a direct impact on loyalty.

Technically, the full ECSI model integrates two sub-models, the structural model and the measurement model. The structural model includes the relations between latent variables and is technically described as follows:

$$\eta = \beta\eta + \gamma\xi + \upsilon \quad (1)$$

where η is the vector of endogenous latent variables (which consists of six latent variables, such as Expectations, Perceived Quality, Perceived Value, Customer Satisfaction, Loyalty and Complaints), and ξ is a vector of an exogenous latent variable (Image). The coefficients of the structural model, β and γ, give the direct impact on a latent variable when there is a unit change in an antecedent latent variable. If the antecedent variable is an exogenous variable, the direct impact is represented by γ, while β represents the direct impact over endogenous variables derived by a unit variation of another endogenous variable. The vector of specification residuals for the endogenous latent variables is represent by ν.

The measurement model defines the relations between the latent variables and the observed indicators (or manifest variables). There are three possible types of measurement models: reflective models (or outwards directed models), formative models, and mixed models. A reflective model exists when the observed variables are assumed to be the reflex of the latent variables. In opposition, the formative model consists of a model where the observed variables are assumed to cause or form the latent variables. The mixed model adopts both models, generally the formative for the exogenous latent variables, while for the other latent variables, the reflective model is used. The ECSI model adopted by Portugal is based on a mixed model, where Image is measured by indicators which are their cause.

The measurement models, when the model is considered reflective, are technically described as follows:

$$x = \Lambda_x\xi + \delta \quad (2)$$

$$y = \Lambda_y\eta + \varepsilon \quad (3)$$

Where x and y are manifest vectors, respectively the exogenous and the endogenous ones. Λ_x and Λ_y are the correspondent weight matrices (loadings) and, finally, δ and ε are measurement error vectors. This situation, where the manifests are reflections of the underlying latent variables, is typical for endogenous variables. If the model is considered formative, it will be more appropriate to specify when the latent variable is formed by the manifest variables, where one has for the exogenous variable ξ, the following equation:

$$\xi = \sum_{l=1}^{G} \lambda_{\xi_l} x_l + \delta_\xi \quad (4)$$

Where λ_{ξ_l} are coefficients of the formative model and δ_ξ are specification errors.

Based on the model described in Figure 1 and formally defined by previous equations, (2) to (4), standardized measurement instruments (questionnaires) are developed for each industry covered by ECSI. The measurement scale is chosen to create enough variation in the data, in order to support a statistical analysis. Furthermore, equidistance between values is crucial. There are also some advantages in choosing a measurement scale without a centred value. In summary, most national indexes within ECSI are based on a 10-point scale. Then, the customer satisfaction index and all other latent variables are transferred to an index ordinary scale of 0 to 100, where 100 denotes the highest possible value.

2.2 *The interlinking between ECSI and AD*

Our main purpose in the ECSI application is to identify the main drivers of customer satisfaction, which are Critical To Satisfy (CTS), in order to get customers' loyalty. After this, it's necessary to translate the requirements identified into FRs (customer mapping). Yang et al. [5] suggested one approach for achieving this goal based on the Quality Function Deployment (QFD) methodology [6]. These authors proposed to perform the QFD phase 1, by mapping CAs to Critical-To-Satisfy (CTS) requirements, and then performe a QFD phase 2 by mapping CTS to FRs. Considering that our ECSI survey allows one to identify the main CAs and their relative importance, the CTS requirements, our proposal reduces the exercise to the construction of only one QFD House (Figure 2). This house is used to display relationship between the Critical CAs (CTS) and FRs.

Afterwards, the AD approach must be used to perform the zigzag mapping between the FRs to the DPs (physical mapping) and to convert the DPs into PVs (process mapping).

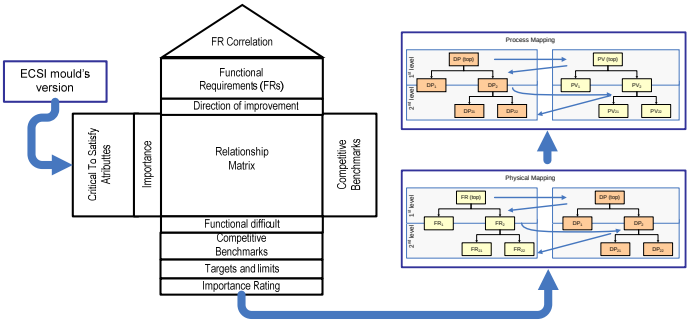

Figure 2. Our conceptual framework approach.

3 CASE OF STUDY

In order to validate the proposed approach, this methodology was applied to a particular industrial sector, namely the Portuguese plastic injection moulds sector.

The design and manufacturing of metallic moulds for plastic parts injection is an interesting case study, because, typically, it involves constant design and production of unrepeatable moulds. This fact is especially interesting because it involves, repeatedly, the placement of new and specific mould orders. In addition, the sector is strongly influenced by their customers. These customers are typically multinational corporations that place enormous pressures on lead times and cost reductions, while simultaneously demanding increased mould quality and reliability.

Moreover, Portugal is one of the world's largest producers of advanced tools for plastic injection and blow moulding, supplying worldwide high-tech companies, namely in the automobile and electronic sectors. This industry is one of the most important sectors of the Portuguese industry. Its importance is not only explained by their contribution to the GDP, but also by the high volume of exportations. In 2004, exportation sales nearly reached 335 million euros, which represent 90% of the production of the Portuguese industry of moulds (372 million euros).

Following the proposed framework, at the exploratory stage, a few number of semi-structured interviews were conducted in Portuguese injection companies that order moulds from the national mould makers (illustrative sample). This interview was made of three parts. The first one concerns the identification of main customers' requirements regarding product quality. In addition, it includes an evaluation of the importance of the moulds' quality for their own manufacturing processes.

The second part of the interview aims to perceive the customer needs and expectations regarding services provided. The last part of the interview intends to know their perspectives of future evolution for the sector with the main objective of evaluating their real satisfaction and loyalty levels. Based on the information gathered from the interviews, it was possible to identify the factors (drivers) that might contribute towards perceived quality of product and service in order to get customer satisfaction. These factors are Quality of mould's design, Quality of the moulds' construction, Cooperation, Resources, Response Capacity and Contracts. Afterwards, and based on the ECSI model, standardised measurement instruments (questionnaires) were developed for the mould makers sector, with the generic questions that are given in Table 1.

Table 1. ECSI model adopted by Portugal.

Latent variables	Observed variables
Image	This mould maker is a reliable and trustworthy company This company is innovative and always looks ahead This company is a customer-oriented company This company has lots of experience in moulds production This company is stable and well established
Expectations	Overall quality of this company Company's capacity in offering moulds that answer to customer needs Moulds makers' reliability and provided service
Quality of the mould's design	The capacity of the mould's design meeting customer's product requirements The mould's design capacity according to the customer's specific injection process Adequacy of constructive solutions The company's accessibility in discussing the mould's design The overall quality of the mould's design
Quality of the moulds' construction	Quality of the structural elements Reliability of the adopted constructive solutions The adequacy of manufacturing processes (type, parameters and tools) to customer requirements The overall quality of the mould's construction
Cooperation	The company's accessibility in sharing responsibilities for the part's quality The following up of the mould performance during it's life cycle Company's pro-activity in collaborating in solving problems during the mould's life cycle Capacity for integrating complementary services
Resources	The technical staff's know-how Level of it's high-tech equipment Quality of the installations
Response capacity	Response capacity to the customer's requirements Capacity in answering quickly to the customer's needs and problems
Contracts	The company's flexibility The fulfilment of the conditions previously agreed

Perceived value	Quality of product/service given the price paid Prices of product/service given the mould's quality
Customer Satisfaction	Overall satisfaction with the company's products and service Considering customer expectations, to what extent have the company fulfilled them How close is the company to customer ideal provider
Complaints	How many times have things gone wrong Identify who have complained How well was the last complaint handled
Loyalty	How likely will you order from this company a new mould Recommend this company to others Sensibility to price changes

Usually, the data for model estimation is obtained from data collected through telephone interviews from a national representative sample of customers who have recently acquired specific products or services. In this project, during the Spring of 2007, data will be collected for a first estimation of this model for the Portuguese mould makers sector. Data collection will be performed in two different ways: (1) by having Portuguese moulds makers send this survey to their customers; (2) by sending it directly to Portuguese and Spanish injection companies (mould makers' customers).

According to the ECSI framework, our entire model is estimated using Partial Least Squares (PLS) criteria. This recommendation is based on the argument that other widely employed frameworks used to estimate SEM make more strict assumptions about the data, specifically about normality [7]. Therefore, traditional estimation methods, like Maximum Likelihood (ML), are not recommended, since the probability density functions of the measured variables are not generally symmetrical, even if one adopts a scale of 1 to 10, and the values of the measured variables are likely to be highly correlated. The PLS algorithms comprise iterative procedures that generate estimates of the observations of the latent variables, the so-called case-values or scores, so that they fit into both the structure of the latent variables and the measurement system. Various versions of the PLS algorithm have been suggested. They mainly differ in the way the case-values are fitted into the structure of the latent variables. Therefore, the latent variables are calculated as weighted averages of their measured variables, and the PLS estimation method calculates the weights in such a way that the resulting model has maximum explanatory power.

4 CONCLUSIONS

This paper proposes a new conceptual framework to be performed as the first stage of the design process. According to Suh, to design a product or a service, firstly it's necessary to perform the customer mapping stage. Even so, the AD theory doesn't comprise special references to the ways in which this should be carried out. And, as opposed to what was proposed for physical and process mapping, it's often impossible to hierarchically map the CAs and the FRs by following a zigzagging process. Moreover, customer requirements of new products are usually inconceivable and hard to acquire accurately and completely. Therefore, our approach aims to fill the knowledge gap between customers and designers, as a way of converting customer requirements into a successful design. In order to validate our proposal, it was applied to the mould's maker Portuguese sector. Hence, firstly an exploratory study was carried out. In this stage, semi-structured interviews were conducted to a few number of injection companies, which are customers of Portuguese moulds' makers. Based on the information gathered, one self-administered questionnaire, based on the ECSI model, was developed in order to determine the CTS requirements. Finally, the CTS requirements identified will then be translated into FRs, by carrying out the construction of one QFD House of Quality. After that, the AD approach will follow by mapping the FRs into DPs, and the DPs into PVs, in a hierarchical manner.

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